Aalborg Universitet

Forces and overtopping on 2. generation wave dragon for Nissum Bredning

Hald, Tue; Frigaard, Peter Bak

Publication date:
2001

Document Version
Publisher's PDF, also known as Version of record

Note
In all the figures 2 - 10 the numbers in the Hs axis must be divided by a factor of 4.5 (the numbers listed are full scale sea states)

efm/ WD Ltd

FORCES AND OVERTOPPING ON 2. GENERATION WAVE DRAGON FOR NISSUM BREDNING

Phase 3 project, Danish Energy Agency

“ Wave Dragon. Reconstruction of an existing model in scale 1:50 and sequentiel tests of changes to the model geometry and mass distribution parameters”

Project no: ENS-51191 / 00-0067

Tue Hald & Peter Frigaard

November 2001

Hydraulic & Coastal Engineering Laboratory
Aalborg University

1. INTRODUCTION

A floating model of the Wave Dragon (WD) was built in autumn 1998 by the Danish Maritime Institute in scale 1:50, see Sørensen and Friis-Madsen (1999) for reference. This model was subjected to a series of model tests and subsequent modifications at Aalborg University. This model is denoted the 1. generation model. Details concerning model tests and modifications are found in Kofoed and Frigaard (1999), Frigaard et al. (1999), Martinelli and Frigaard (1999a) and Martinelli and Frigaard (1999b). Based on the previous findings the WD has been redesigned by Friis-Madsen and Armstrong Technology (2000) and subsequently tested at Aalborg University, see Hald and Lynggaard (2001a, 2001b).

The purpose of this report is to summarize forcing and overtopping on the redesigned WD model, in the following termed the 2. generation WD model. More details concerning the results can be found in Hald and Lynggaard (2001b). The results will establish a basis for the development of the 1:4.5 scale prototype planned for testing in Nissum Bredning, a sea inlet on the Danish West Coast. For comparison also results obtained using the 1. generation are referred in this report.

2. SCALING

All quantities describing the geometrical and hydraulic conditions are scaled to Nissum Bredning conditions. The Froude scaling law applies for scaling the data from model to prototype and accordingly all quantities are scaled as follows:

Quantity	Scaling law	Scaling factor
Length	λ_L	4.5
Time	$\lambda_L^{0.5}$	$4.5^{0.5}$
Discharge	$\lambda_L^{2.5}$	$4.5^{2.5}$
Volume, mass, forces	λ_L^{3}	4.5^{3}
Stiffness	λ_L^{2}	4.5^{2}
Mass moment of inertia	λ_L^{5}	4.5^{5}

3. MODEL CONFIGURATION

The structural configuration of the 2. generation WD is based on the geometry of the Wave Dragon prototype designed for Nissum by Armstrong Technology (2000). In Table I the different mass distribution parameters of the 2. generation model are shown and compared to the 1. generation model. The location of the centre of gravity is measured from the stern in surge, CL in sway and from the lower level of the turbine corridor.

Table I. Mass distribution parameters.

Model:		1. generation	2. generation	
Scale:		1:4.5	1:4.5	
Mass:	[t]	155	128	177
Centre of gravity:				
Surge	[m]	5.1	7.1	8.2
Sway	[m]	0.0	0.0	0.0
Heave	[m]	1.4	1.6	1.5
Mass moment of Inertia:				
Yaw	[kg m^2]	$5.85\ 10^6$	$9.16\ 10^6$	$9.38\ 10^6$
Pitch	[kg m^2]	$1.07\ 10^6$		$3.00\ 10^6$
Roll	[kg m^2]	$5.58\ 10^6$		

In Figure 1 the WD in the normal configuration is depicted and each of the force registration points can be seen. In the cables used to tension the two reflector arms forces are registered in the across cable A, the total mooring force was measured in one single line where the structure was acchored, and finally, three force components were measured in the junction between the right reflector and the shoulder. Movements were registrered for three dregrees of freedom (heave, pitch and surge). Finally, also the amount of overtopping water in the reservoir was registered.

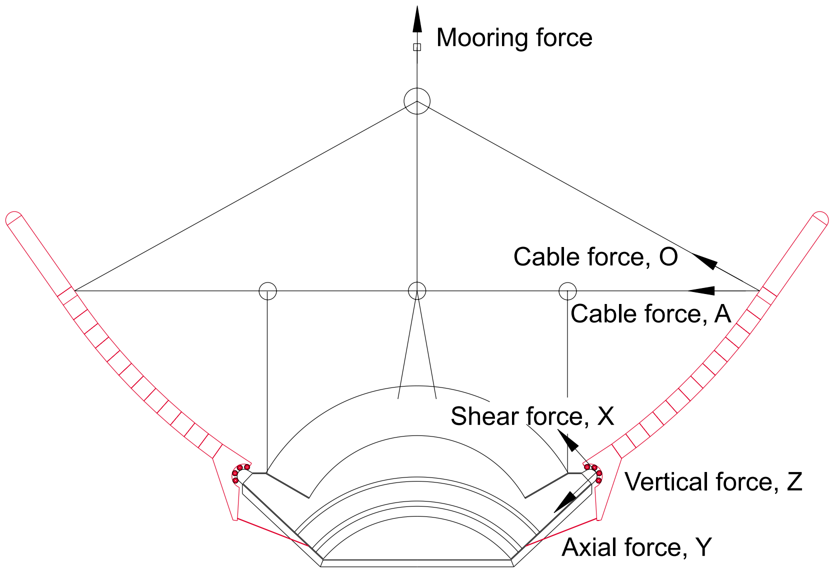


Figure 1. Normal configuration of Wave Dragon and force registration positions.

The hydraulic behaviour of the WD is not only dependent of the structural geometry and mass distribution but depends also on the stiffness of tension cables linking the two reflector arms and the stiffness of the moorings. WD is intended moored to a single pile in front by a single cable, see Figure 1. This cable is split in two in proximity of the WD body and in the 1. generation model the mooring elasticity of the central cable was 70 kN/m and finally, from the stern two mooring lines are fixed to the sea bed. The two tension cables fix the reflector arms to the central mooring cable, both cables hawing an elasticity of 25 kN/m. For the 2. generation model these stifnesses have been kept. Both the tension cables and the mooring cable has been pretensioned to approximately 11 kN and 16.5 kN respectively.

4. FORCING

Waves were registered by two resistance type wave gauges placed on either side of the WD outside the reflector arms. The measured waves were not always coincident to the target values, thus registered forces, movements and overtopping were referred to measured waves.

Mooring forces were registred by a load cell designed and manufactured by Aalborg University whereas cable forces and forces in the junction were registered by a 3D load cell and a z-gauge designed and manufactured by Danish Maritime Institute. Two characteristic values were retrieved from the signals: the root mean square (rms) value F_{rms} for fatigue design and the average of the highest 1/250 of the peak forces $F_{1/250}$ being a representative for the maximum peak force.

In the following only peak forces as function of wave height are shown

4.1. MOORING FORCES

Figure 2 show mooring force as function of wave height.

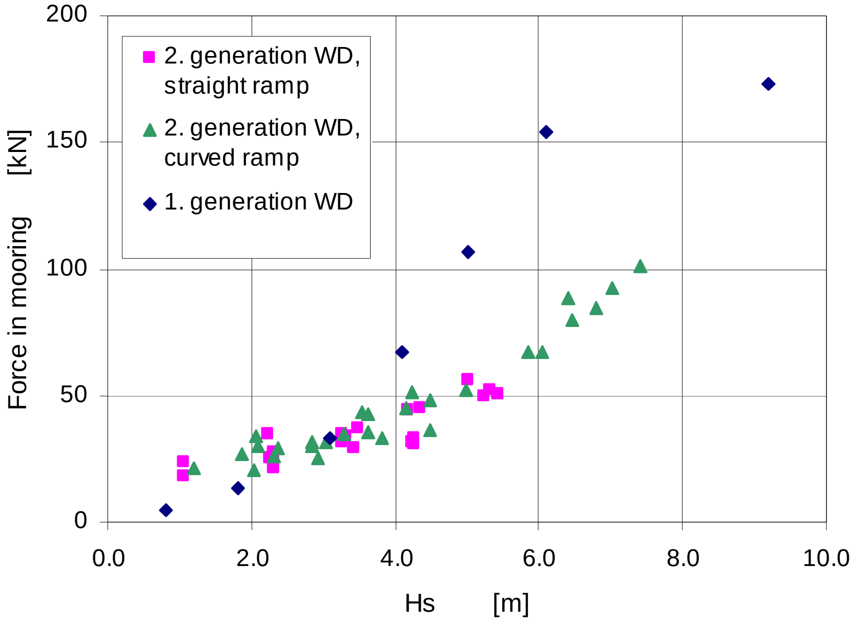


Figure 2. Mooring force for Wave Dragon prototype, scale 1:4.5.

4.2. Forces in cables

Figure 3 and 4 show forces in cables A and O as function of wave height.

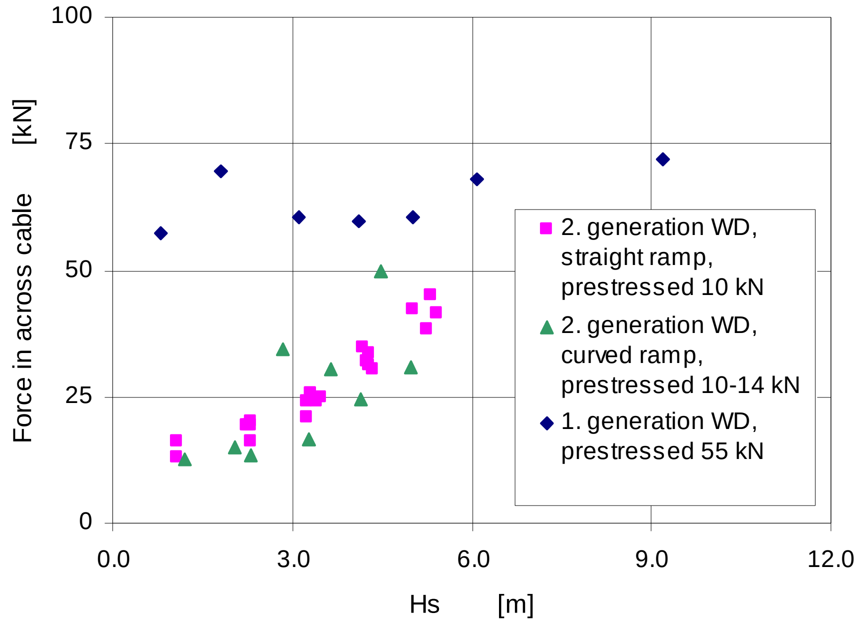


Figure 3. Force in across cable A for Wave Dragon prototype, scale 1:4.5.

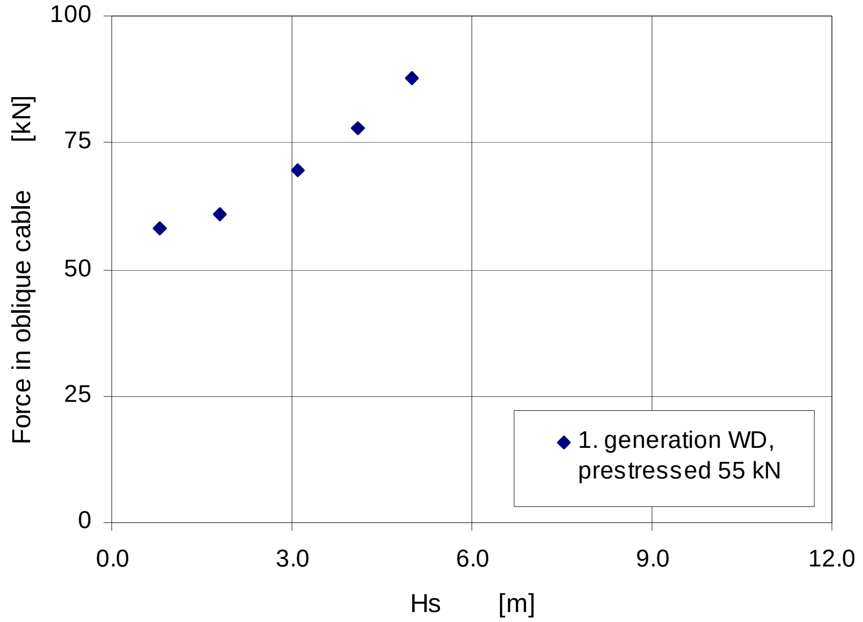


Figure 4. Force in oblique cable O for Wave Dragon prototype, scale 1:4.5.

4.3. Forces on shoulder hinge

Figure 5 - 10 shows force components acting on shoulder hinge as function of wave height.

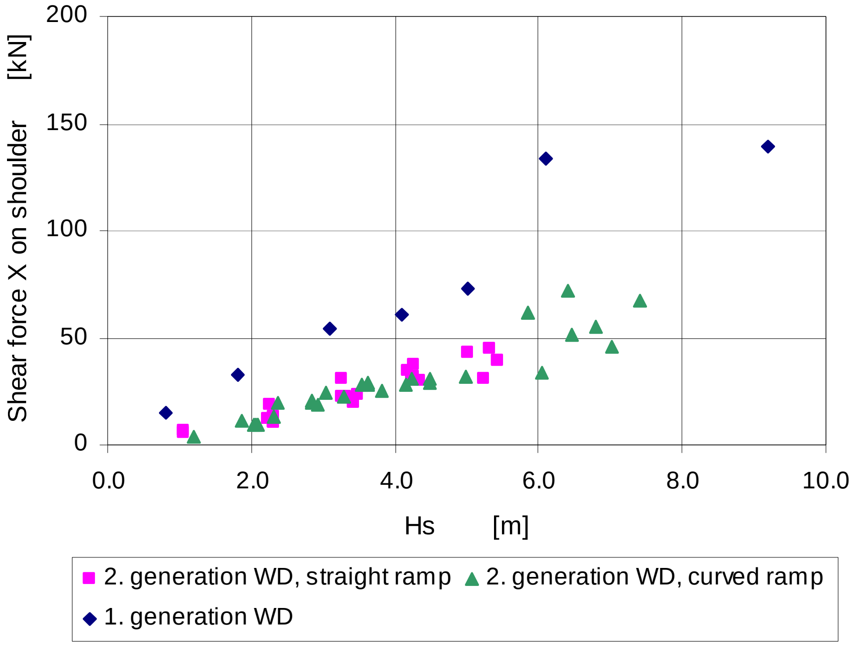


Figure 5. Shear force X on shoulder for Wave Dragon prototype, scale 1:4.5.

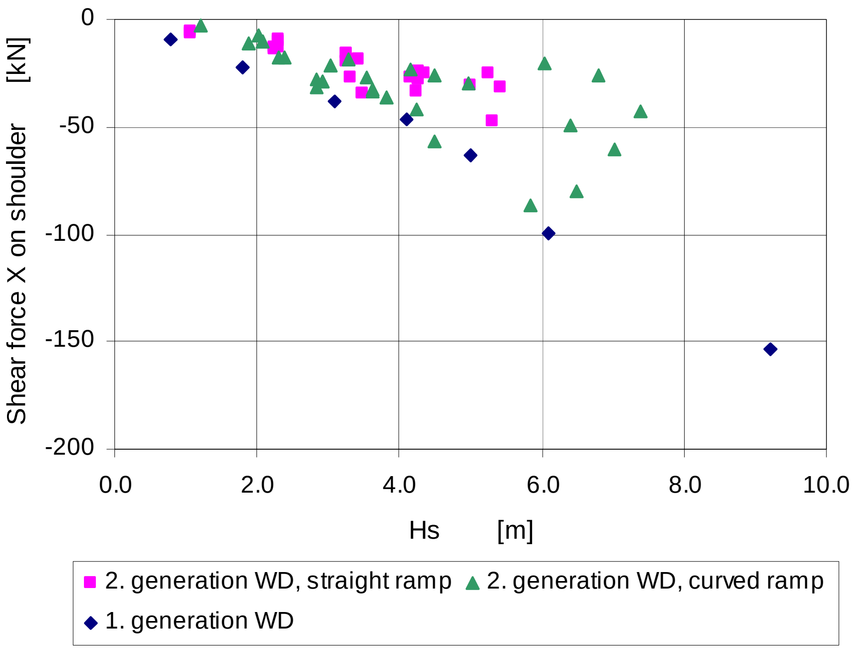


Figure 6. Shear force X on shoulder for Wave Dragon prototype, scale 1:4.5.

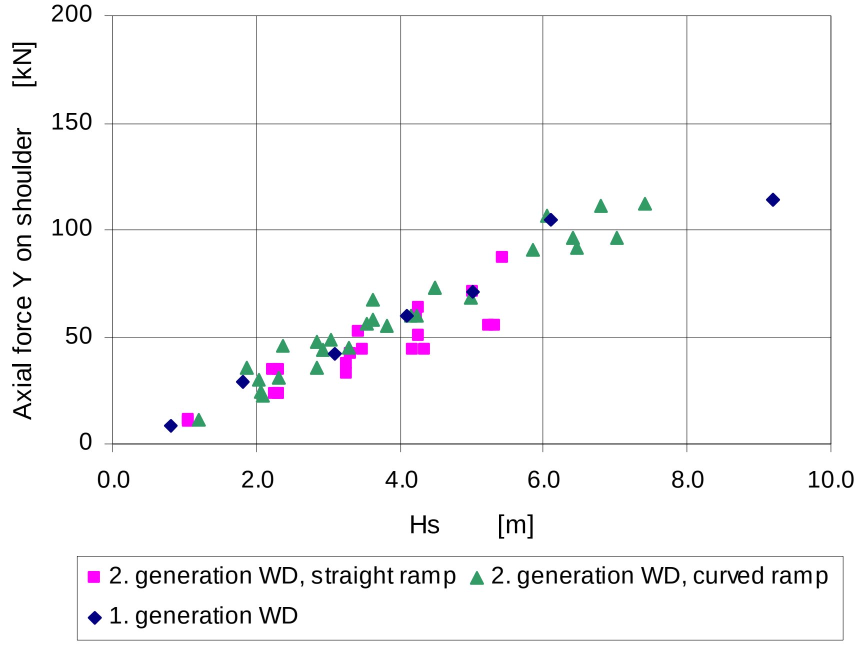


Figure 7. Axial force Y on shoulder for Wave Dragon prototype, scale 1:4.5.

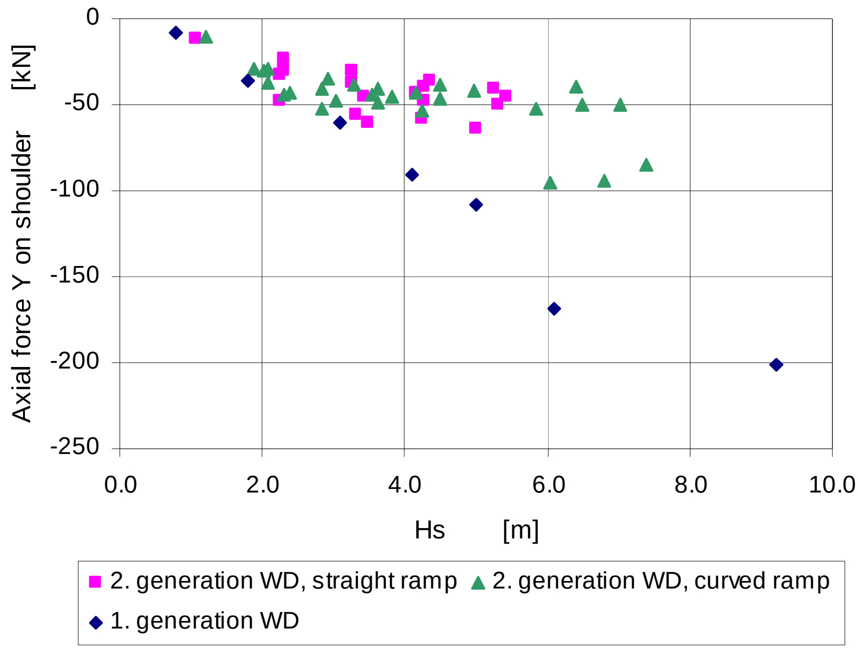


Figure 8. Axial force Y on shoulder for Wave Dragon prototype, scale 1:4.5.

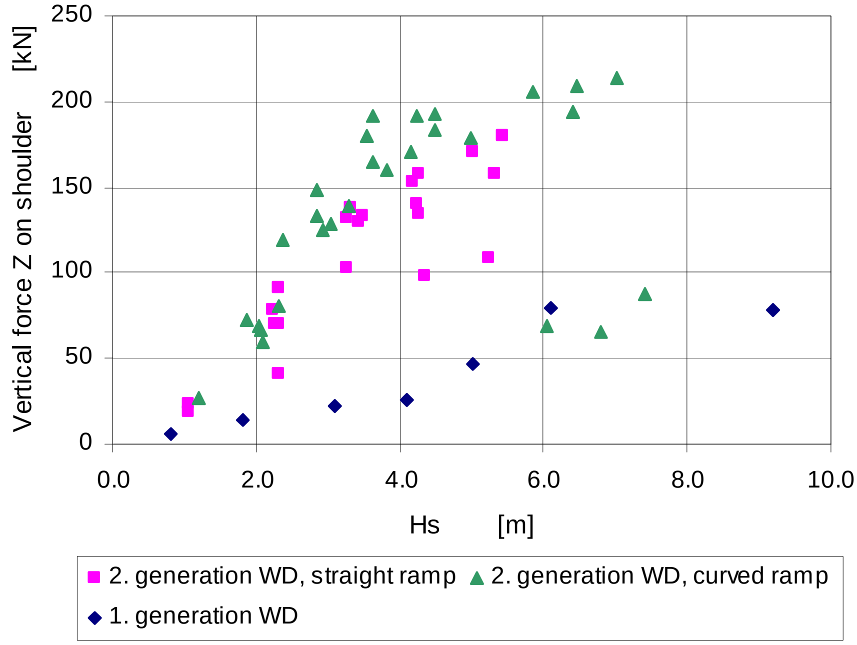


Figure 9. Vertical force Z on shoulder for Wave Dragon prototype, scale 1:4.5.

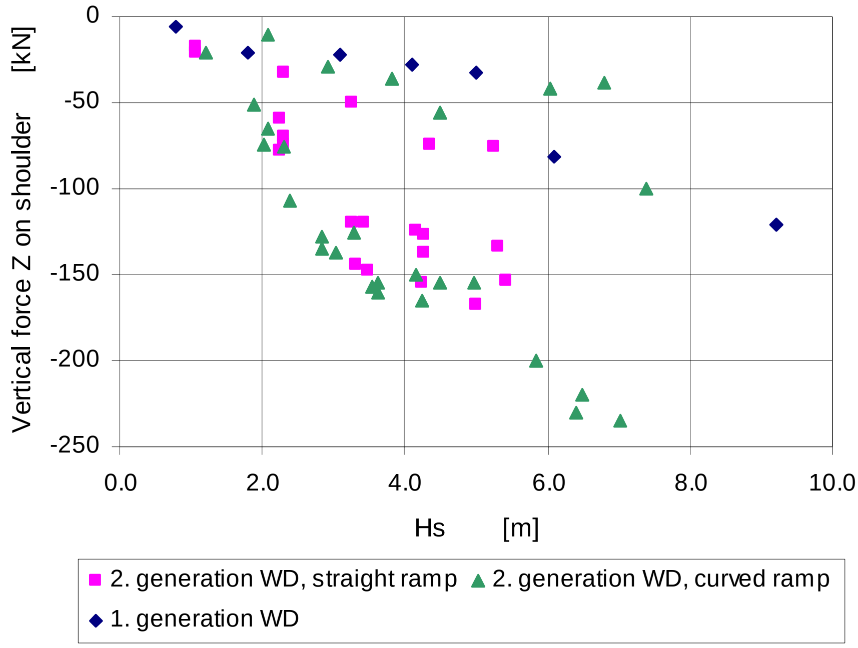


Figure 10. Vertical force Z on shoulder for Wave Dragon prototype, scale 1:4.5.

5. OVERTOPPING

According to the previous tests measured values of overtopping were non-dimensionalized and presented in the following form:

$$Q^* = 0.017\,exp(-48R^*) \qquad \text{(eq. 1)}$$

where,

$$Q^* = \frac{q\sqrt{s_{op}/2\pi}}{\sqrt{gH_s^3L}}$$

$$R^* = \frac{R_c}{H_s}\sqrt{\frac{s_{op}}{2\pi}}$$

q = discharge due overtopping

H_s = significant wave height

L = ramp width = 86.6 m

s_{op} = wave steepness defined as $s_{op} = H_s/L_{op}$

L_{op} = deep water wave length defined as $L_{op} = \frac{g}{2\pi}T_p^2$

T_p = peak period

R_c = Mean value of crest freeboard relative to MWL

Overtopping results obtained using the 2. generation model are shown in Figure 2 as well as the overtopping relation for the 1.generation model (eq. 1).

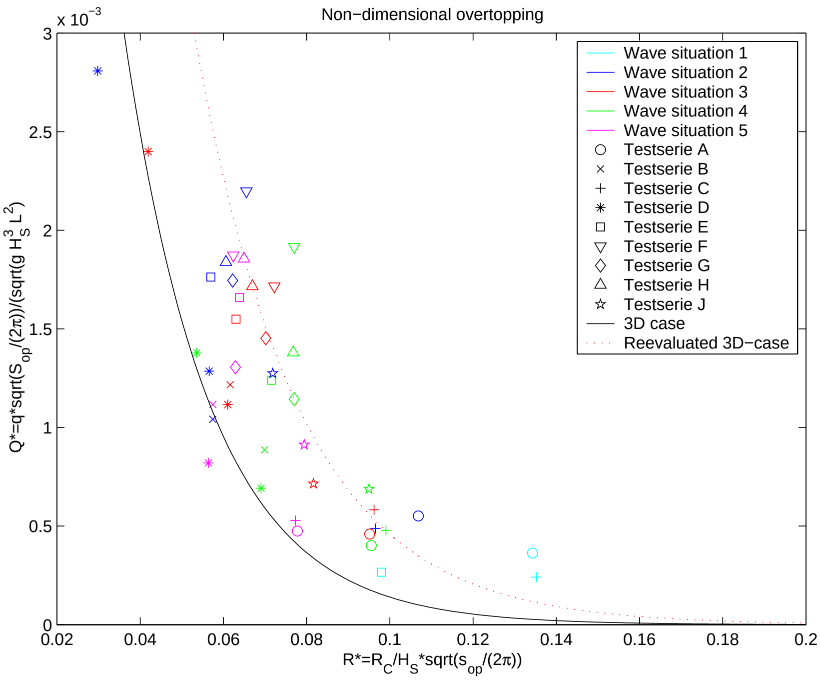


Figure 11. Dimensionless overtopping relation.

Also in Figure 8 a reevaluated overtopping relation is shown based on measurements obtanied with the new doubly-curved overtopping ramp. The new overtopping equation is modified to:

$$Q^* = 0.025\,exp(-40R^*) \qquad \text{(eq. 2)}$$

7. REFERENCES

Armstrong Technology, *Wave Dragon Prototype – Basic structural design*, Internal report, JOULE-CRAFT project: "Low pressure turbine and control equipment for wave energy converters / Wave Dragon", 2000

Frigaard, P., Lauridsen, H., Andreasen, M., *Minimizing pitch movement of the Wave Dragon*, Hydraulics and Coastal Engineering Laboratory, Aalborg University, 1999.

Hald, T., Lynggaard, J., *Ombygning af Wave Dragon* (in Danish), Hydraulics & Coastal Engineering Laboratory, Aalborg University, DEA phase 3 report, project no: ENS-51191 / 00-0067, 2001a.

Hald, T., Lynggaard, J., *Hydraulic model tests on modified Wave Dragon*, Hydraulics & Coastal Engineering Laboratory, Aalborg University, DEA phase 3 report, project no: ENS-51191 / 00-0067, 2001b.

Kofoed, J.P., Frigaard, P., *Evaluation of the hydraulic response of the Wave Dragon*, Hydraulics & Coastal Engineering Laboratory, Aalborg University, DEA phase A test report, 1999.

Martinelli, L., Frigaard, P. *The Wave Dragon: 3D overtopping tests on a floating model*, Hydraulics and Coastal Engineering Laboratory, Aalborg University, Wave Dragon - DEA and CRAFT project test report, 1999.

Martinelli, L., Frigaard, P. *The Wave Dragon: tests on a modified model*, Hydraulics and Coastal Engineering Laboratory, Aalborg University, Wave Dragon - DEA and CRAFT project test report, 1999.

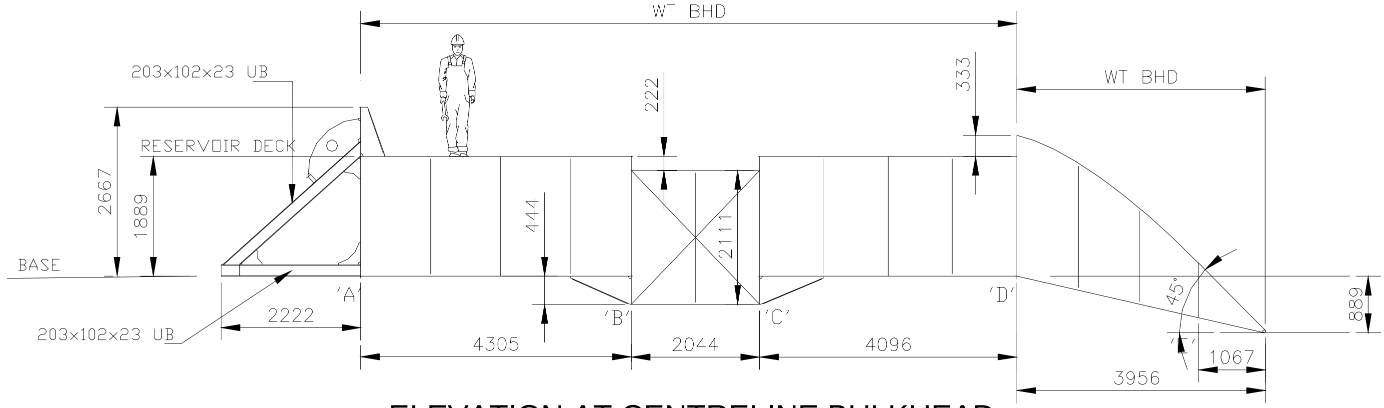
Sørensen, H.C., Friis-Madsen, E., *Wave Dragon – Tests to evaluate the hydraulic response*, DEA phase A, report phase A, 1999.

Appendix A

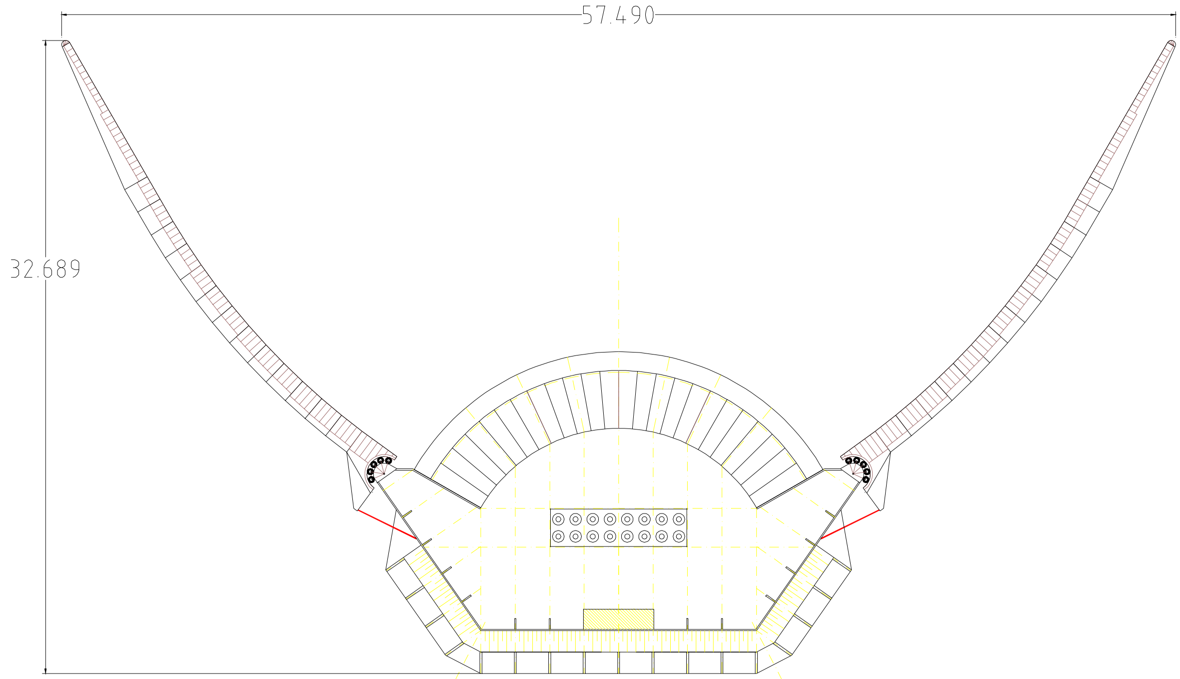
Cross sectional and plan view of Wave Dragon

LÖWENMARK
Consulting Engineers F.R.I
Blegdamsvej 4 • DK-2200 Copenhagen N • Phone: +45 35 37 02 11 • Fax:: +45 35 37 45 37

E. Friis-Madsen Aps. Reg. nr. 53078
Member of the Danish Association of Consulting Engineers, FIDIC, EFCA



ELEVATION AT CENTRELINE BULKHEAD



Plane view, Wave Dragon model scale 1:4,5 - measures in meters.